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(54) **DETERMINING LINEAR PREDICTIVE CODING FILTER PARAMETERS FOR ENCODING A VOICE SIGNAL**

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Related U.S. Application Data

(63) Continuation of application No. 10/446,314, filed on May 28, 2003, now Pat. No. 6,782,359, which is a continuation of application No. 10/083,237, filed on Feb. 26, 2002, now Pat. No. 6,611,799, which is a continuation of application No. 09/805,634, filed on Mar. 14, 2001, now Pat. No. 6,385,577, which is a continuation of application No. 09/441,743, filed on Nov. 16, 1999, now Pat. No. 6,223,152, which is a continuation of application No. 08/950,658, filed on Oct. 15, 1997, now Pat. No. 6,006,174, which is a continuation of application No. 08/670,986, filed on Jun. 28, 1996, now abandoned, which is a continuation of application No. 08/104,174, filed on Aug. 9, 1993, now abandoned, which is a continuation of application No. 07/592,330, filed on Oct. 3, 1990, now Pat. No. 5,235,670.

(51) **Int. Cl.**
G10L 19/04 (2006.01)

(52) **U.S. Cl.** **704/219**; 704/220; 704/222

(58) **Field of Classification Search** 704/219, 704/220, 221, 222, 223; 375/245
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,618,982	A	10/1986	Horvath et al.
4,669,120	A	5/1987	Ono
4,776,015	A	10/1988	Takeda et al.
4,815,134	A	3/1989	Picone et al.

(Continued)

FOREIGN PATENT DOCUMENTS

WO WO 86 08 72 6 6/1986

OTHER PUBLICATIONS

Proc. ICASSP '82, A New Model of LPC Excitation for Producing Natural-Sounding Speech at Low Bit Rates, B.S. Atal and J.R. Remde, pp 614-617, Apr., 1982, no day.

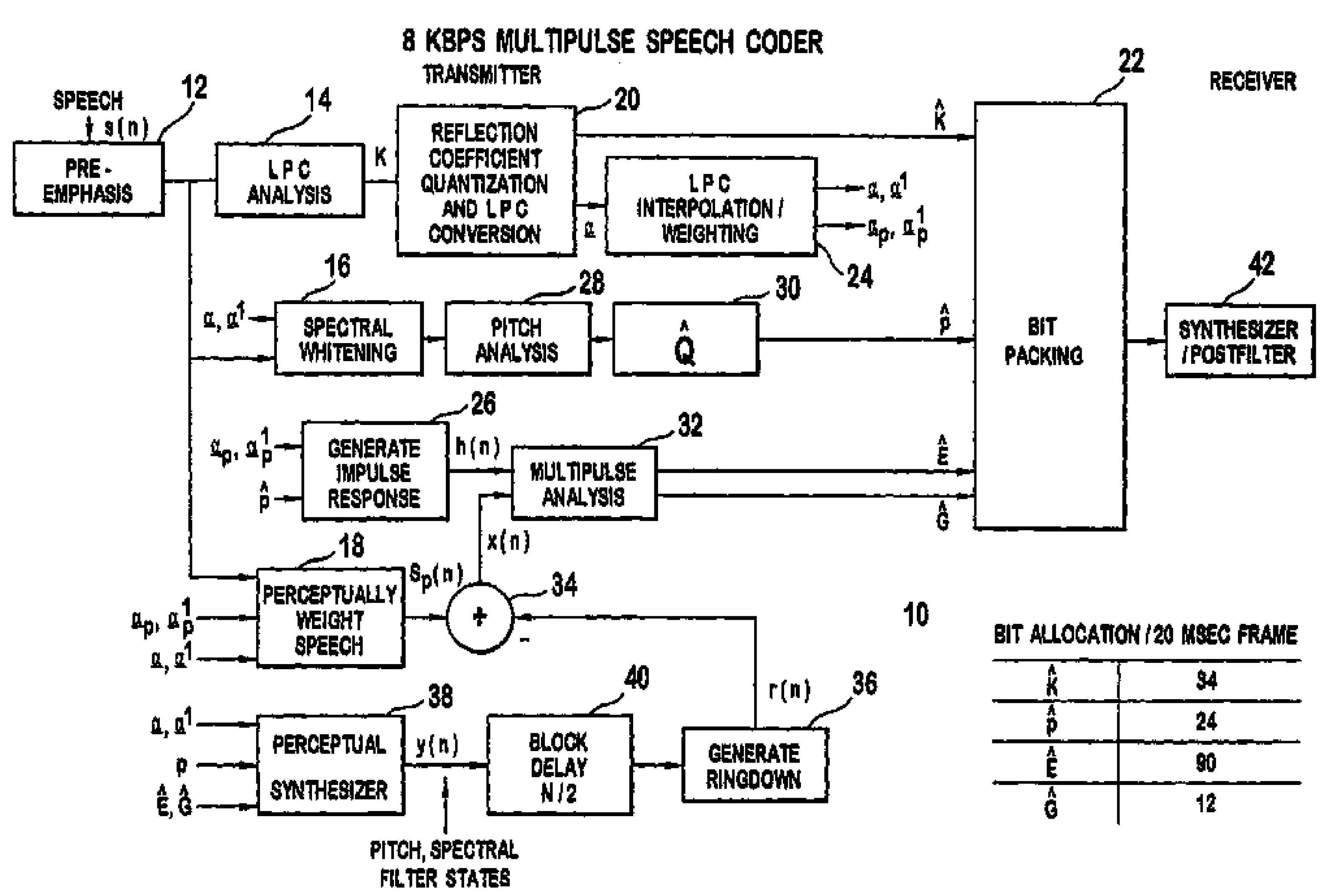
(Continued)

Primary Examiner—Susan McFadden
(74) *Attorney, Agent, or Firm*—Volpe and Koenig, P.C.

(57) **ABSTRACT**

The present invention is a method for determining linear predictive coding filter parameters for encoding a voice signal. The method includes sampling a voice signal, grouping the samples into a plurality of frames, generating a plurality of reflection coefficients for each frame of samples, quantizing the reflection coefficients, generating spectral coefficients from the quantized reflection coefficients, selecting a quantized reflection coefficient having the smallest log-spectral distance between a quantized spectrum, and an unquantized spectrum and, converting the selected quantized reflection coefficient to linear predictive coding (LPC) filter coefficient.

10 Claims, 12 Drawing Sheets



U.S. PATENT DOCUMENTS

4,845,753	A	7/1989	Yasunaga	
4,868,867	A	9/1989	Davidson et al.	
4,890,327	A	12/1989	Bertrand et al.	
4,980,916	A	12/1990	Zinser	
4,991,213	A	2/1991	Wilson	
5,001,759	A	3/1991	Fukui	
5,027,405	A	6/1991	Ozawa	
5,235,670	A	8/1993	Lin et al.	
5,265,167	A	11/1993	Akamine et al.	
5,307,441	A	4/1994	Tzeng	
5,327,520	A *	7/1994	Chen	704/219
5,568,514	A *	10/1996	McCree et al.	375/245
5,675,702	A *	10/1997	Gerson et al.	704/223
5,999,899	A	12/1999	Robinson	
6,246,979	B1 *	6/2001	Carl	704/219

OTHER PUBLICATIONS

Proc. ICASSP '84, Improving Performance of Multi-Pulse Coders at Low Bit Rates, S. Singhal and B.S. Atal, paper 1.3, Mar. 1984, no day.

Proc. ICASSP '84, Efficient Computation and Encoding of the Multiple Excitation for LPC, M. Berouti et al., paper 10.1, Mar. 1984, no day.

Proc. ICASSP '86, Implementation of Multi-Pulse Coder on a Single Chip Floating-Point Signal Processor, H. Alrutz, paper 44.3, Apr. 1986, no day.

Digital Telephony, John Bellamy, pp 153-154, 1991, no month day.

Veeneman et al., "Computationally Efficient Stochastic Coding of Speech," 1990, IEEE 40th Vehicular Technology Conference, May 1990, pp. 331-335, no day.

* cited by examiner

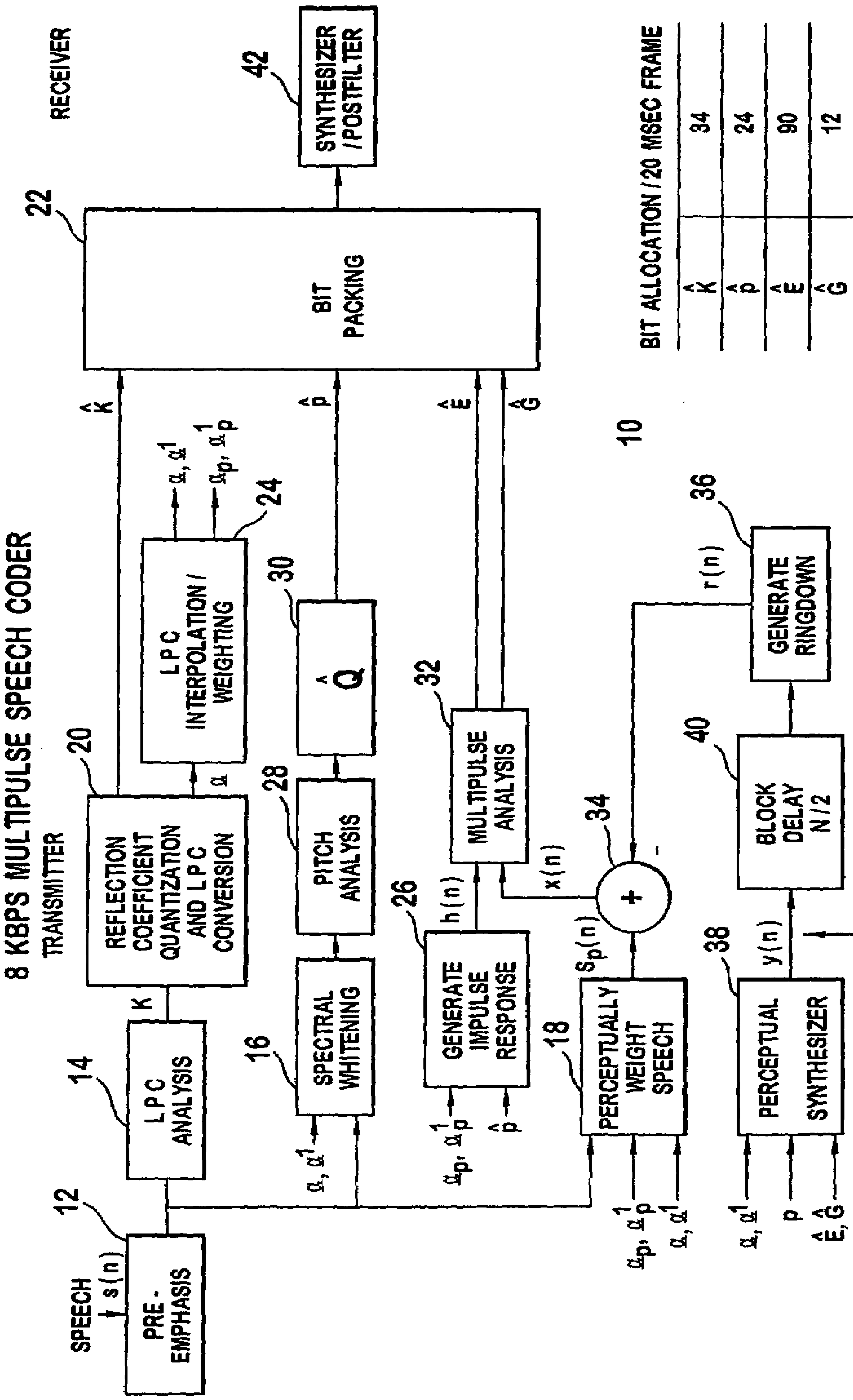

8 KBPS MULTIPULSE SPEECH CODER
TRANSMITTER
RECEIVER
SPEECH
s(n)
PRE-EMPHASIS
12
LPC ANALYSIS
14
K
REFLECTION COEFFICIENT QUANTIZATION AND LPC CONVERSION
20
LPC INTERPOLATION / WEIGHTING
24
SPECTRAL WHITENING
16
PITCH ANALYSIS
28
Q
30
GENERATE IMPULSE RESPONSE
26
h(n)
MULTIPULSE ANALYSIS
32
x(n)
PERCEPTUALLY WEIGHT SPEECH
18
Sp(n)
34
r(n)
GENERATE RINGDOWN
36
BLOCK DELAY N/2
40
PERCEPTUAL SYNTHESIZER
38
y(n)
PITCH, SPECTRAL FILTER STATES
BIT PACKING
22
SYNTHESIZER /POSTFILTER
42
10
BIT ALLOCATION / 20 MSEC FRAME
K 34
p 24
E 90
G 12

FIG. 1

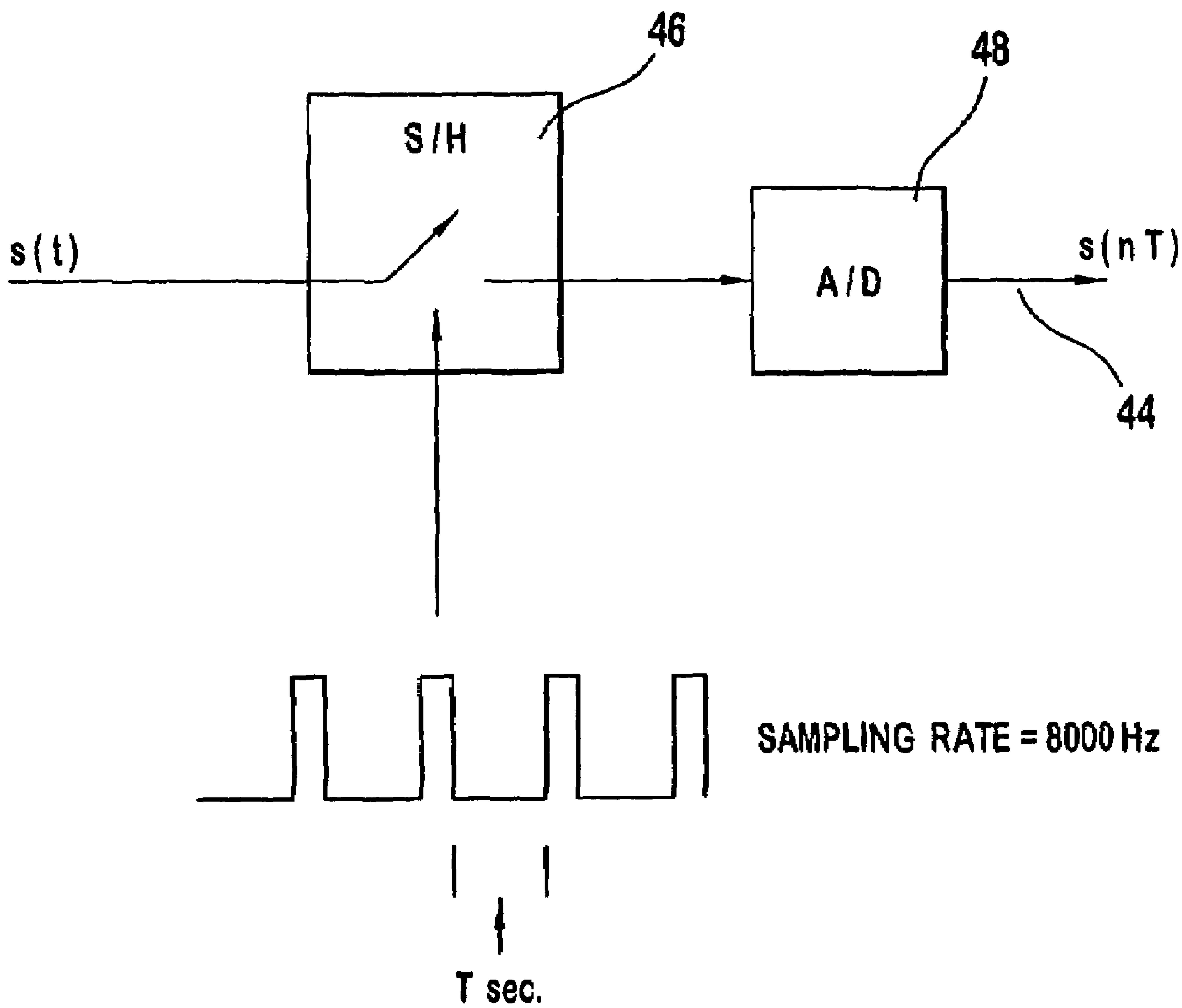


FIG. 2

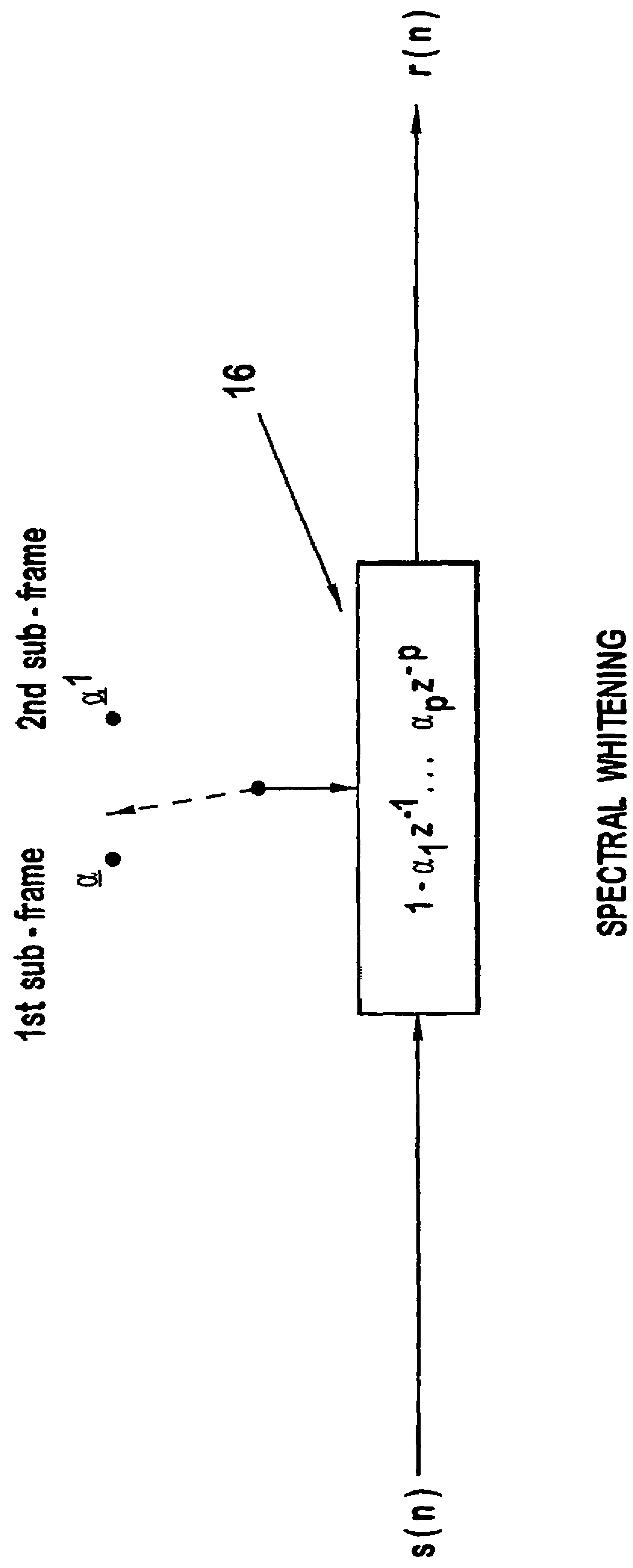

r(n)
16
1st sub-frame
2nd sub-frame
$\underline{\alpha}$
$\underline{\alpha}^1$
$1 - \alpha_1 z^{-1} \ldots \alpha_p z^{-p}$
SPECTRAL WHITENING
s(n)

FIG. 3

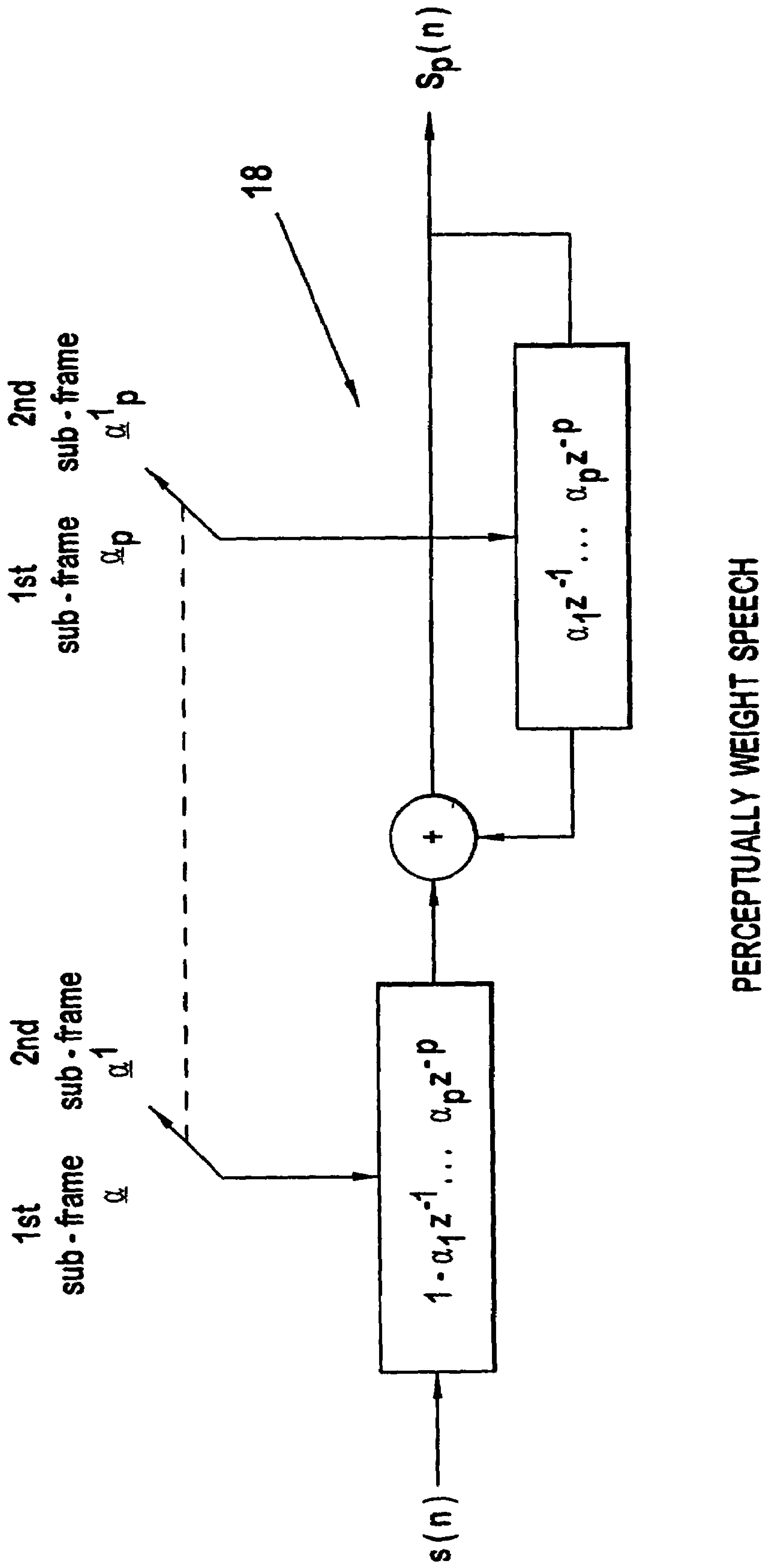
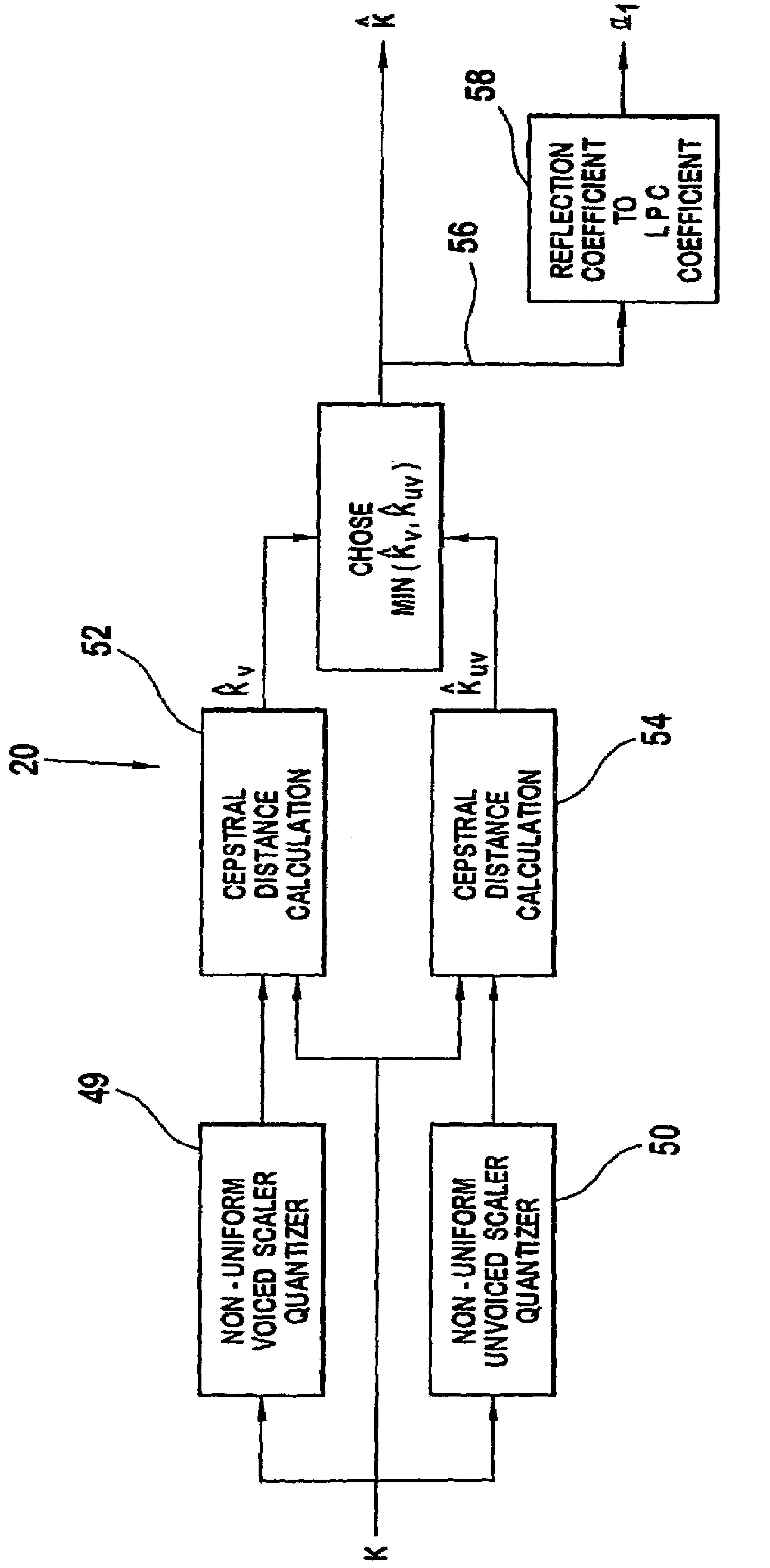
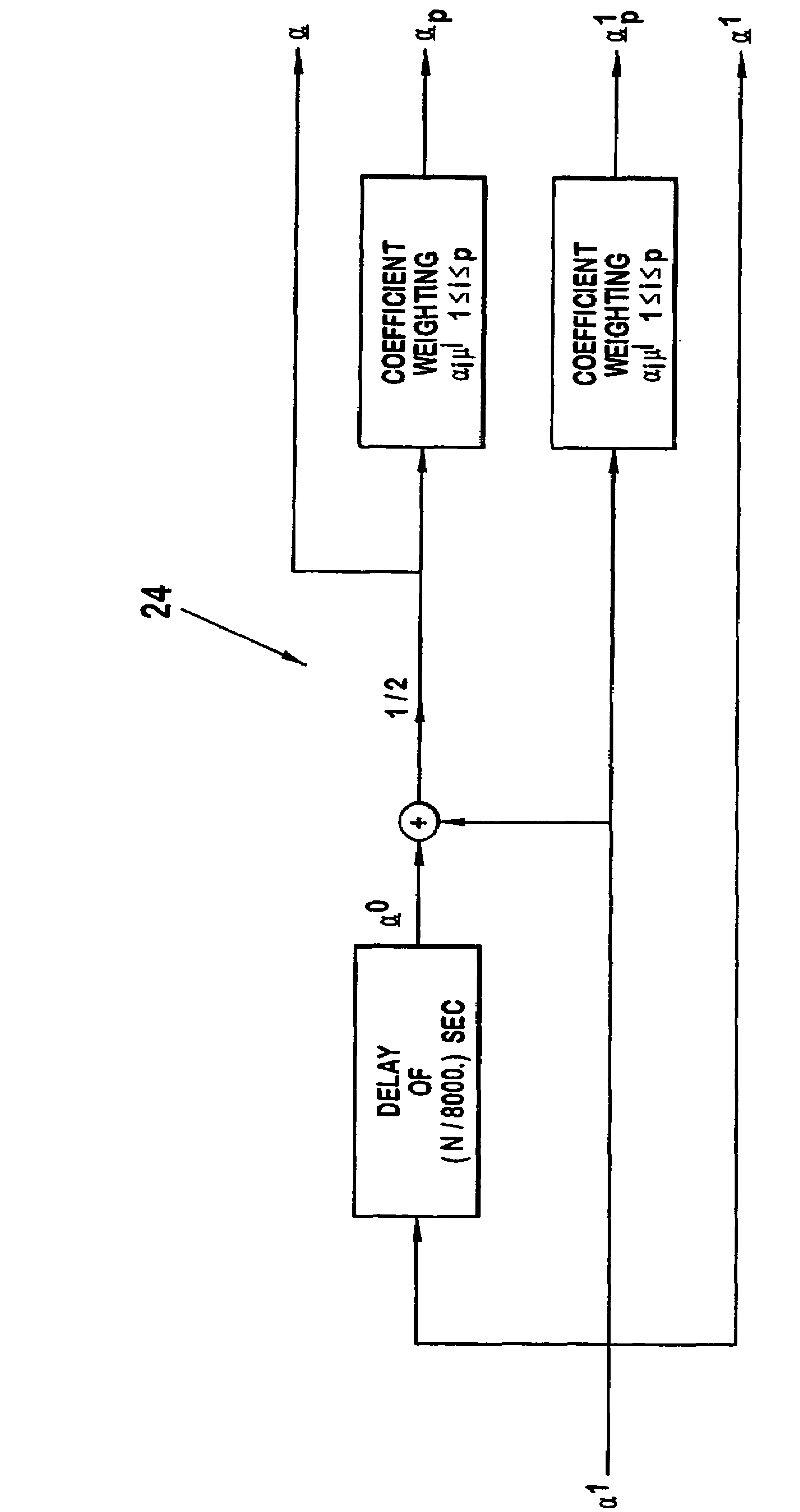

s(n)
1 - α1z-1 ... αpz-p
1st sub-frame α
2nd sub-frame α1
+
α1z-1 ... αpz-p
1st sub-frame αp
2nd sub-frame α1p
18
Sp(n)
PERCEPTUALLY WEIGHT SPEECH

FIG. 4



REFLECTION COEFFICIENT QUANTIZATION

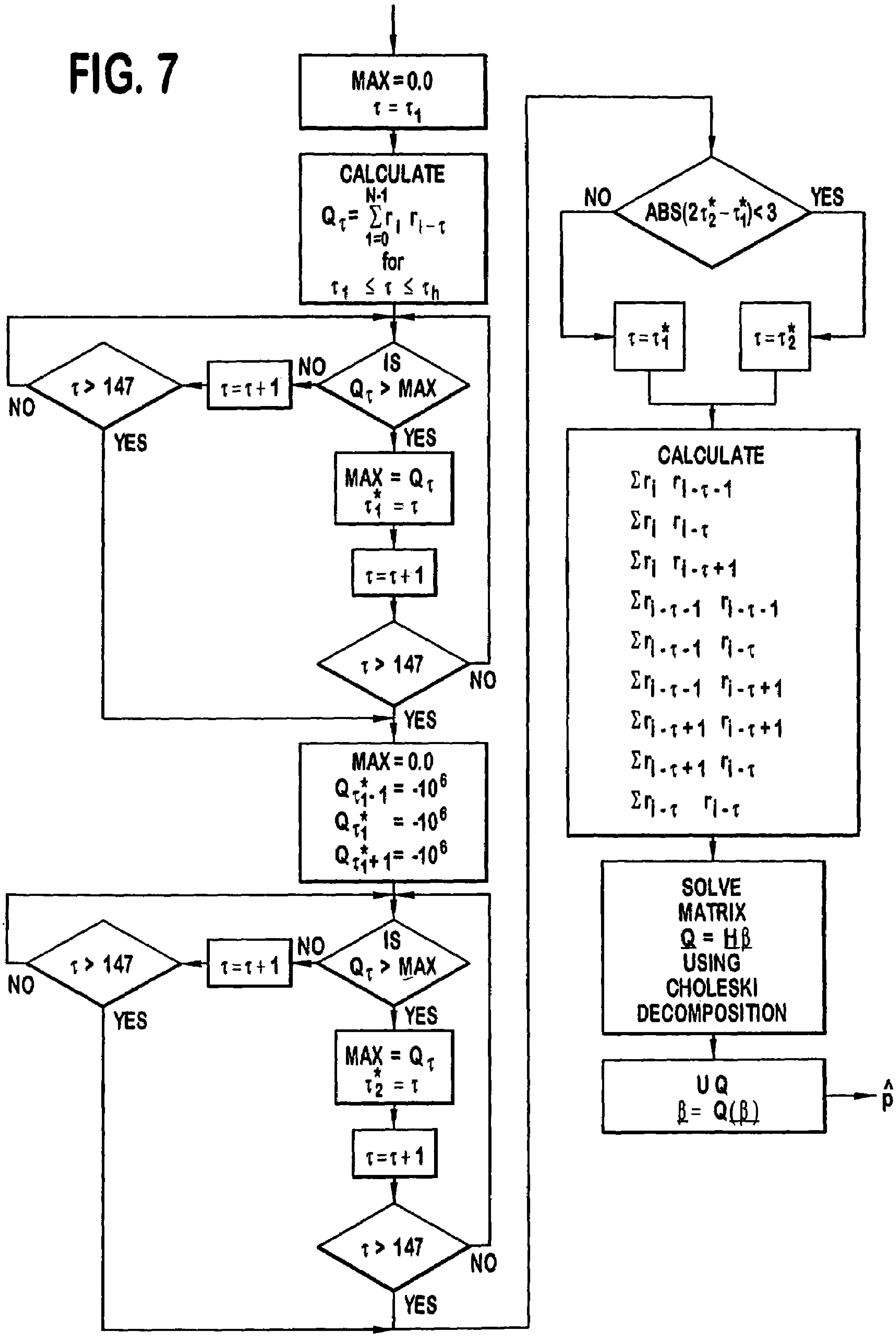
FIG. 5



L P C INTERPOLATION / WEIGHTING

FIG. 6

FIG. 7


MAX=0.0
τ = τ1
CALCULATE
Qτ= Σ ri ri−τ
N-1
1=0
for
τ1 ≤ τ ≤ τh
IS
Qτ > MAX
NO
YES
τ=τ+1
τ > 147
NO
YES
MAX = Qτ
τ1* = τ
τ=τ+1
τ > 147
NO
YES
MAX=0.0
Qτ1*-1 = -10^6
Qτ1* = -10^6
Qτ1*+1= -10^6
IS
Qτ > MAX
NO
YES
τ=τ+1
τ > 147
NO
YES
MAX = Qτ
τ2* = τ
τ=τ+1
τ > 147
NO
YES
ABS(2τ2*−τ1*)<3
NO
YES
τ=τ1*
τ=τ2*
CALCULATE
Σri ri-τ-1
Σri ri-τ
Σri ri-τ+1
Σri-τ-1 ri-τ-1
Σri-τ-1 ri-τ
Σri-τ-1 ri-τ+1
Σri-τ+1 ri-τ+1
Σri-τ+1 ri-τ
Σri-τ ri-τ
SOLVE
MATRIX
Q = Hβ
USING
CHOLESKI
DECOMPOSITION
U Q
β= Q(β)
p̂

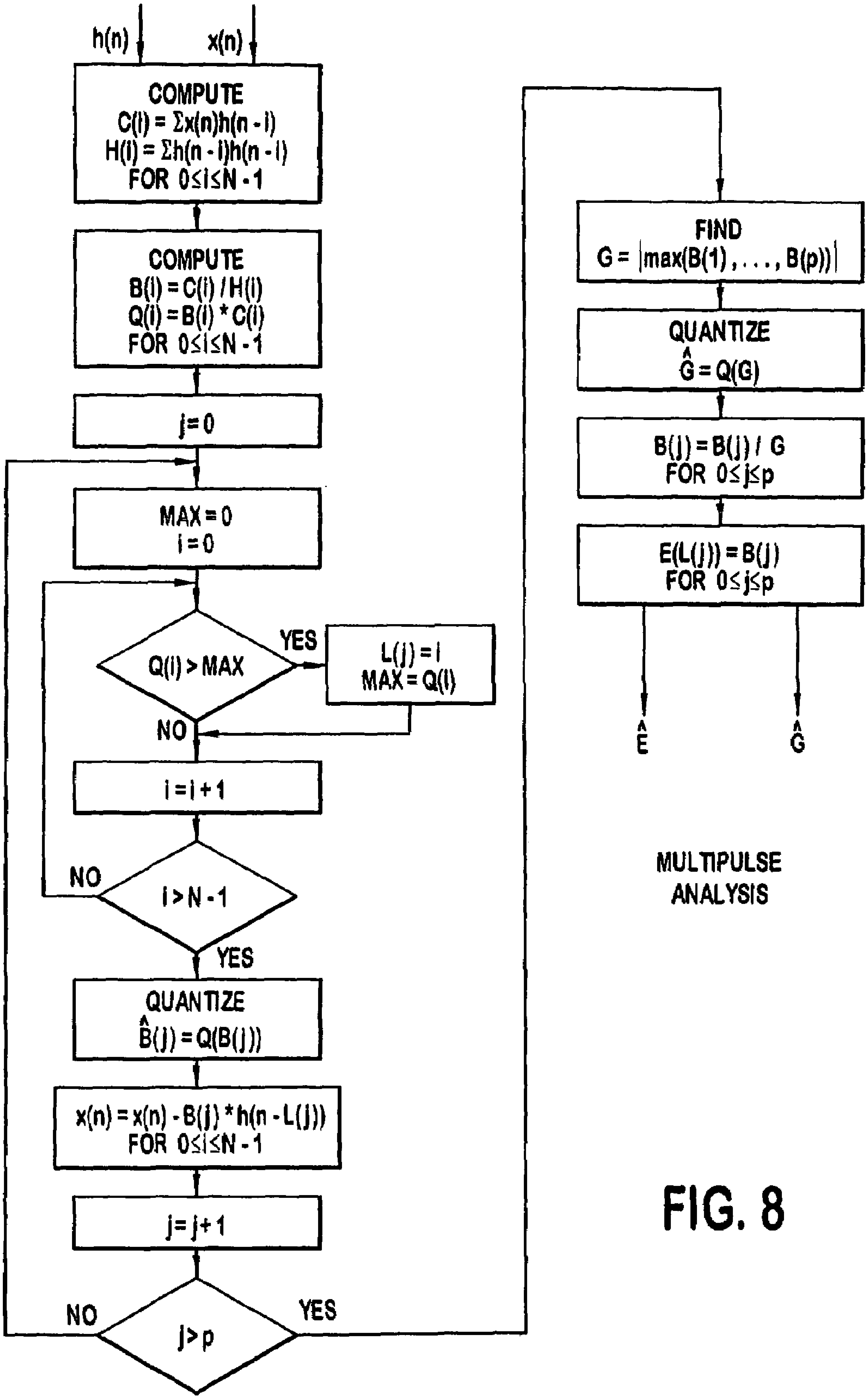
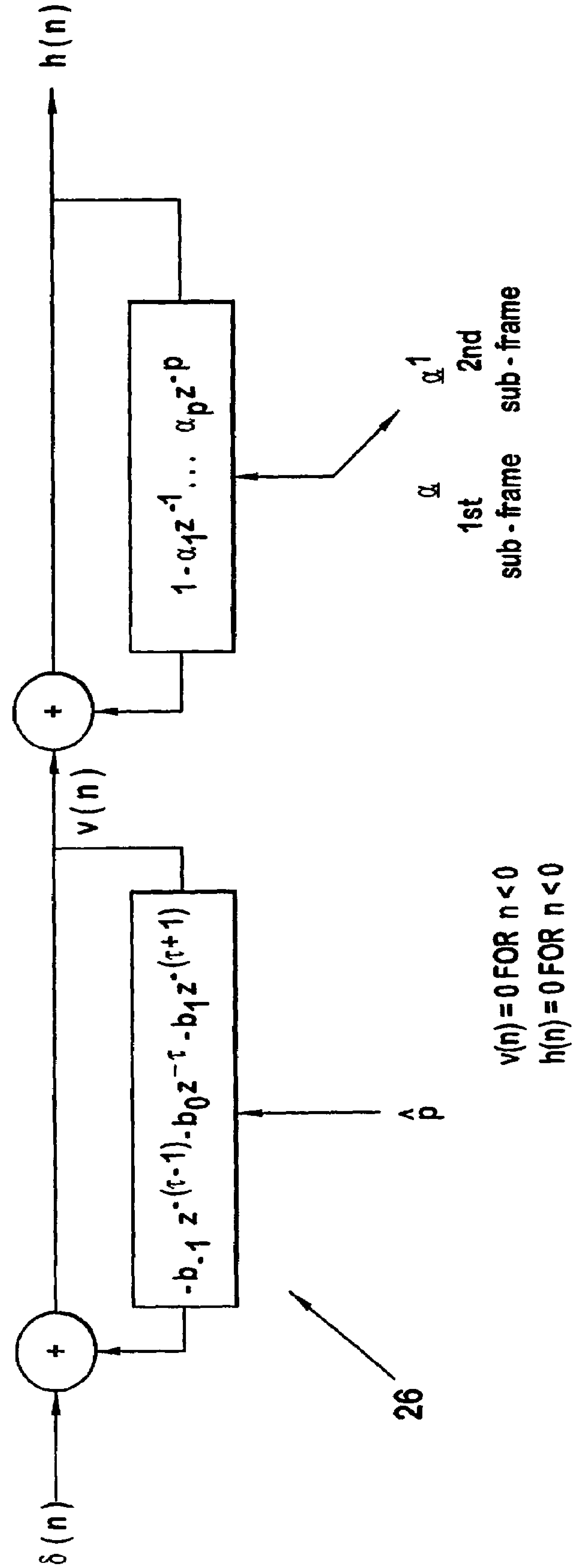
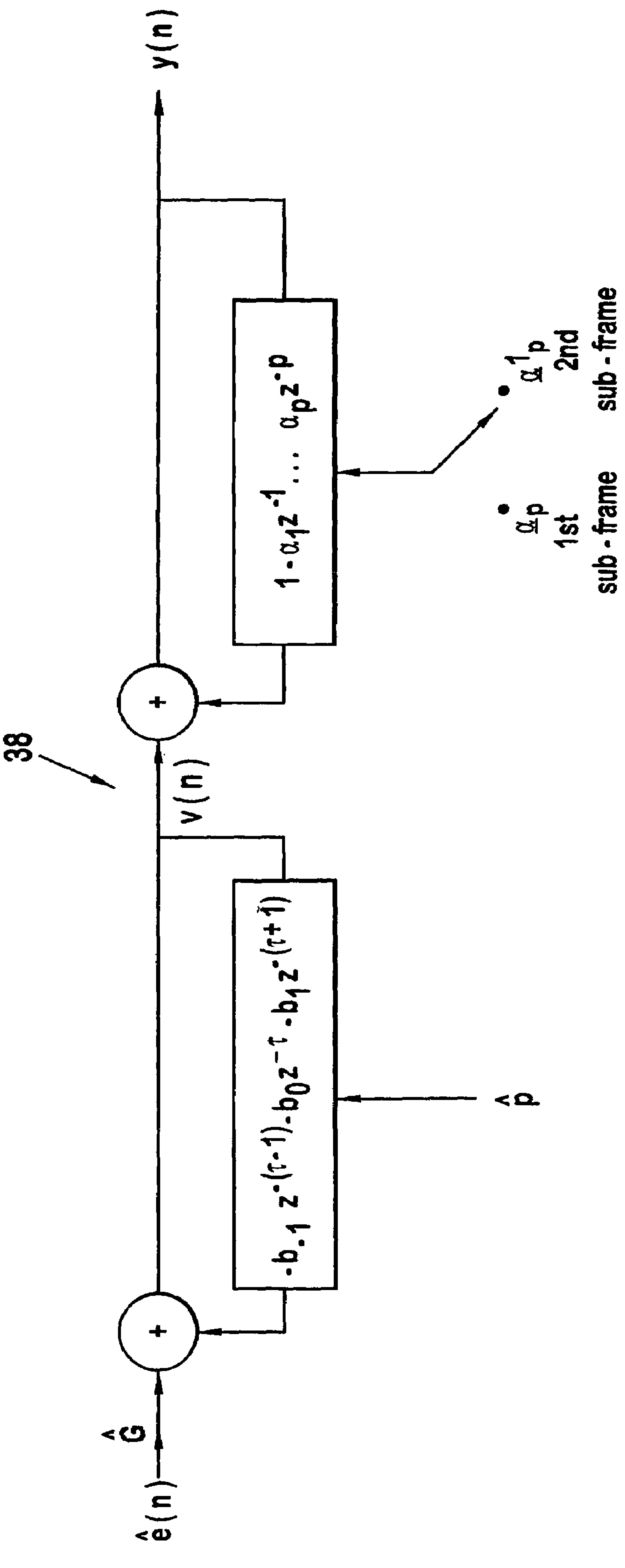

h(n)
x(n)
COMPUTE
C(i) = Σx(n)h(n - i)
H(i) = Σh(n - i)h(n - i)
FOR 0≤i≤N - 1
COMPUTE
B(i) = C(i) / H(i)
Q(i) = B(i) * C(i)
FOR 0≤i≤N - 1
j = 0
MAX = 0
i = 0
Q(i) > MAX
YES
L(j) = i
MAX = Q(i)
NO
i = i + 1
NO
i > N - 1
YES
QUANTIZE
B̂(j) = Q(B(j))
x(n) = x(n) - B(j) * h(n - L(j))
FOR 0≤i≤N - 1
j = j + 1
NO
j > p
YES
FIND
G = |max(B(1), . . . , B(p))|
QUANTIZE
Ĝ = Q(G)
B(j) = B(j) / G
FOR 0≤j≤p
E(L(j)) = B(j)
FOR 0≤j≤p
Ê
Ĝ
MULTIPULSE
ANALYSIS

FIG. 8



GENERATE IMPULSE RESPONSE

FIG. 9



PERCEPTUAL SYNTHESIZER

FIG. 10

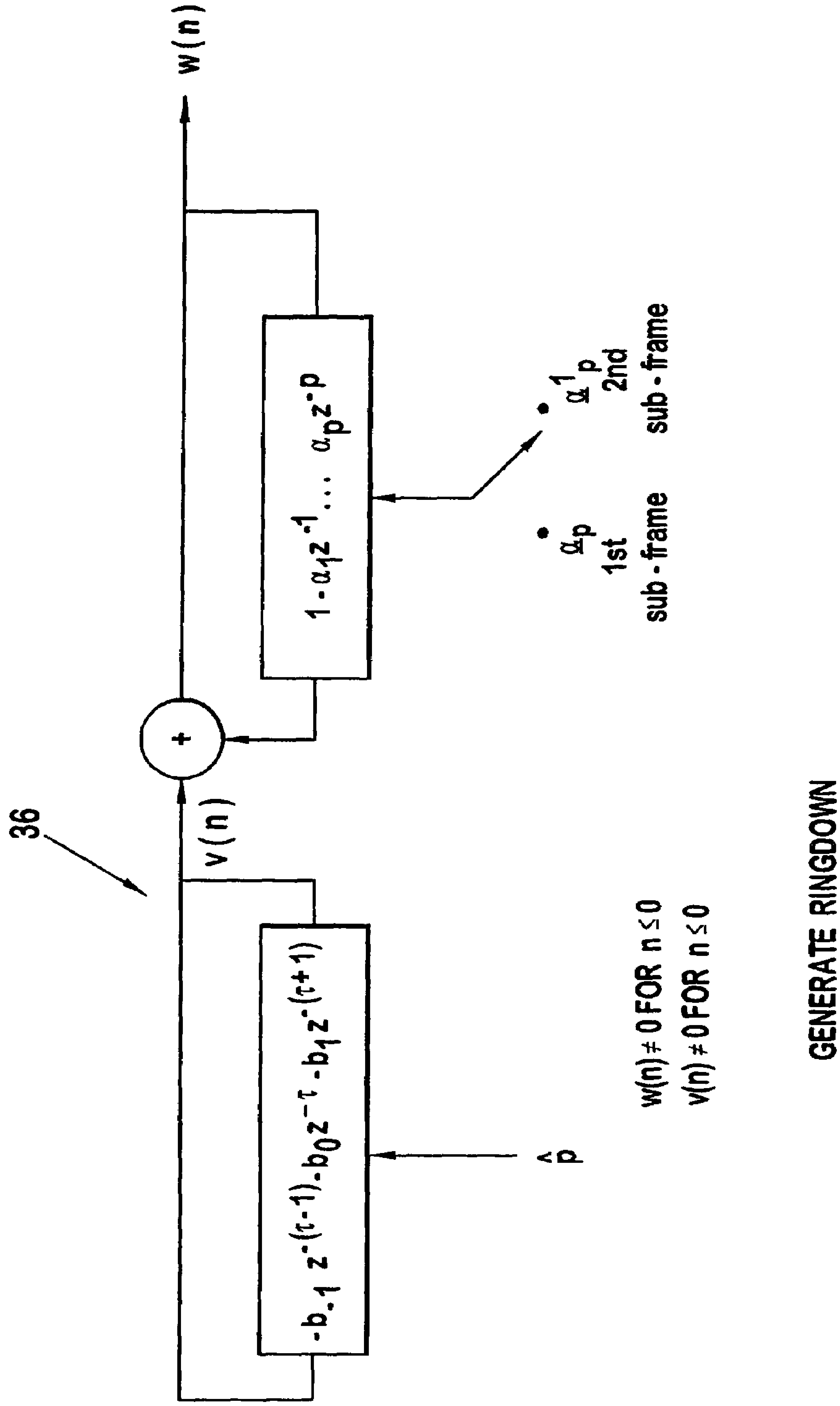

w(n)
36
v(n)
+
1 - α1z-1... αpz-p
αp
1st
sub-frame
α1p
2nd
sub-frame
-b-1 z-(τ-1) - b0z-τ - b1z-(τ+1)
p̂
w(n) ≠ 0 FOR n ≤ 0
v(n) ≠ 0 FOR n ≤ 0
GENERATE RINGDOWN

FIG. 11

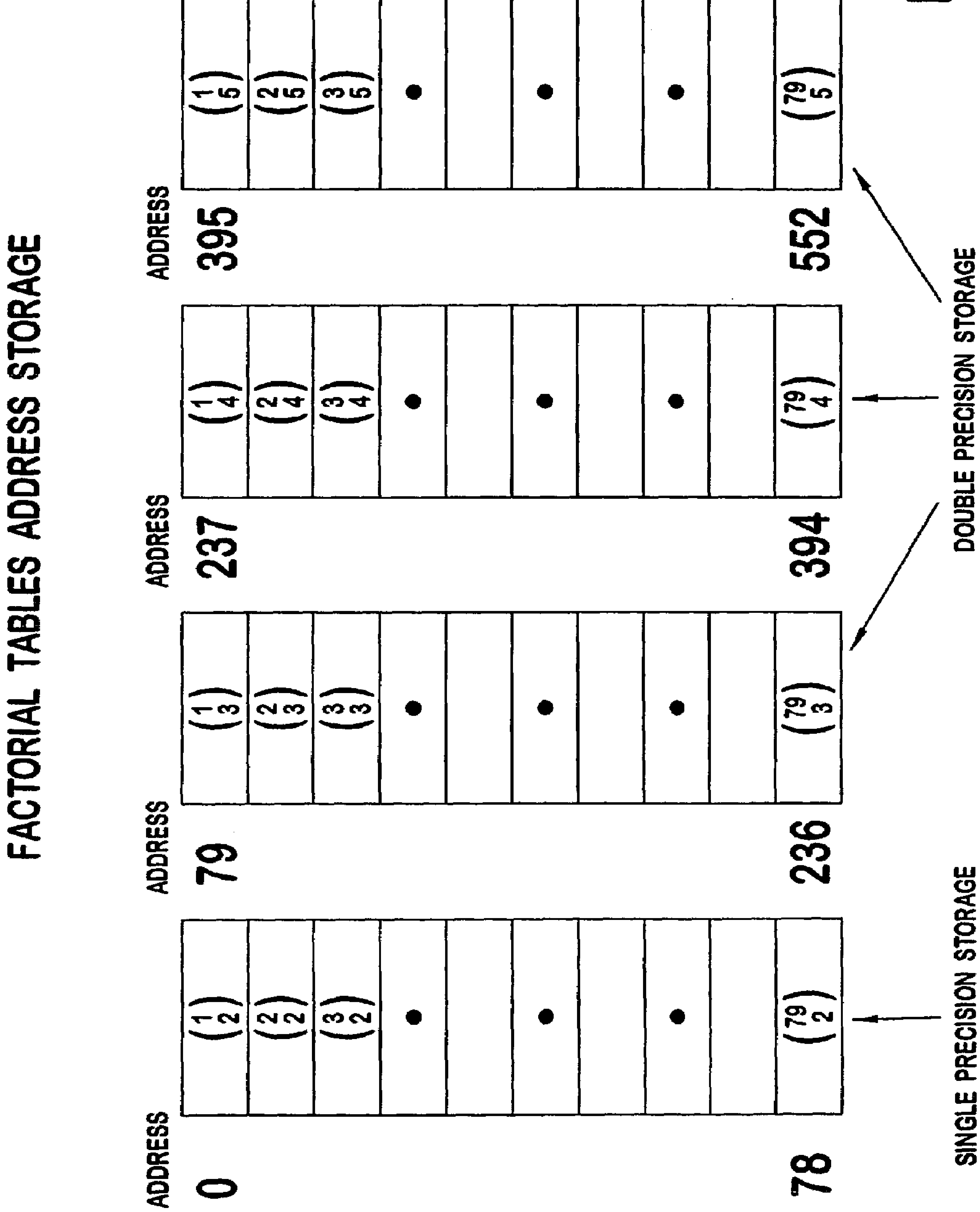

FACTORIAL TABLES ADDRESS STORAGE
ADDRESS
0
78
79
236
237
394
395
552
$\binom{1}{2}$ $\binom{2}{2}$ $\binom{3}{2}$ $\binom{79}{2}$
$\binom{1}{3}$ $\binom{2}{3}$ $\binom{3}{3}$ $\binom{79}{3}$
$\binom{1}{4}$ $\binom{2}{4}$ $\binom{3}{4}$ $\binom{79}{4}$
$\binom{1}{5}$ $\binom{2}{5}$ $\binom{3}{5}$ $\binom{79}{5}$
SINGLE PRECISION STORAGE
DOUBLE PRECISION STORAGE

FIG. 12

DETERMINING LINEAR PREDICTIVE CODING FILTER PARAMETERS FOR ENCODING A VOICE SIGNAL

This application is a continuation of U.S. patent application Ser. No. 10/083,237, filed Feb. 26, 2002 now U.S. Pat. No. 6,611,799 issued Aug. 26, 2003, which is a continuation of U.S. patent application Ser. No. 09/805,634, filed Mar. 14, 2001, now U.S. Pat. No. 6,385,577 issued May 7, 2002, which is a continuation of U.S. patent application Ser. No. 09/441,743, filed Nov. 16, 1999, now U.S. Pat. No. 6,223,152 issued Apr. 24, 2001, which is a continuation of U.S. patent application Ser. No. 08/950,658, filed Oct. 15, 1997, now U.S. Pat. No. 6,006,174 issue Dec. 21, 1999, which is a file wrapper continuation of U.S. patent application Ser. No. 08/670,986, filed Jun. 28, 1996 now abandoned, which is a file wrapper continuation of U.S. patent application Ser. No. 08/104,174, filed Aug. 9, 1993 now abandoned, which is a continuation of U.S. patent application Ser. No. 07/592,330, filed Oct. 3, 1990, now U.S. Pat. No. 5,235,670 issued Aug. 10, 1993, which applications are incorporated herein by reference.

BACKGROUND

This invention relates to digital voice coders performing at relatively low voice rates but maintaining high voice quality. In particular, it relates to improved multipulse linear predictive voice coders.

The multipulse coder incorporates the linear predictive all-pole filter (LPC filter). The basic function of a multipulse coder is finding a suitable excitation pattern for the LPC all-pole filter which produces an output that closely matches the original speech waveform. The excitation signal is a series of weighted impulses. The weight values and impulse locations are found in a systematic manner. The selection of a weight and location of an excitation impulse is obtained by minimizing an error criterion between the all-pole filter output and the original speech signal. Some multipulse coders incorporate a perceptual weighting filter in the error criterion function. This filter serves to frequency weight the error which in essence allows more error in the format regions of the speech signal and less in low energy portions of the spectrum. Incorporation of pitch filters improve the performance, of multipulse speech coders. This is done by modeling the long term redundancy of the speech signal thereby allowing the excitation signal to account for the pitch related properties of the signal.

SUMMARY

Linear predictive coding (LPC) filter parameters are determined for use in encoding a voice signal. Samples of a speech signal using a z-transform function are pre-emphasized. The pre-emphasized samples are analyzed to produce LPC reflection coefficients. The LPC reflection coefficients are quantized by a voiced quantizer and by an unvoiced quantizer producing sets of quantized reflection coefficients. Each set is converted into respective spectral coefficients. The set which produces a smaller lag-spectral distance is determined. The determined set is selected to encode the voice signal.

BRIEF DESCRIPTION OF THE DRAWING(S)

FIG. **1** is a block diagram of an 8 kbps multipulse LPC speech coder.

FIG. **2** is a block diagram of a sample/hold and A/D circuit used in the system of FIG. **1**.

FIG. **3** is a block diagram of the spectral whitening circuit of FIG. **1**.

FIG. **4** is a block diagram of the perceptual speech weighting circuit of FIG. **1**.

FIG. **5** is a block diagram of the reflection coefficient quantization circuit of FIG. **1**.

FIG. **6** is a block diagram of the LPC interpolation/weighting circuit of FIG. **1**.

FIG. **7** is a flow chart diagram of the pitch analysis block of FIG. **1**.

FIG. **8** is a flow chart diagram of the multipulse analysis block of FIG. **1**.

FIG. **9** is a block diagram of the impulse response generator of FIG. **1**.

FIG. **10** is a block diagram of the perceptual synthesizer circuit of FIG. **1**.

FIG. **11** is a block diagram of the ringdown generator circuit of FIG. **1**.

FIG. **12** is a diagrammatic view of the factorial tables address storage used in the system of FIG. **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

This invention incorporates improvements to the prior art of multipulse coders, specifically, a new type LPC spectral quantization, pitch filter implementation, incorporation of pitch synthesis filter in the multipulse analysis, and excitation encoding/decoding.

Shown in FIG. **1** is a block diagram of an 8 kbps multipulse LPC speech coder, generally designated **10**.

It comprises a pre-emphasis block **12** to receive the speech signals s(n). The pre-emphasized signals are applied to an LPC analysis block **14** as well as to a spectral whitening block **16** and to a perceptually weighted speech block **18**.

The output of the block **14** is applied to a reflection coefficient quantization and LPC conversion block **20**, whose output is applied both to the bit packing block **22** and to an LPC interpolation/weighting block **24**.

The output from block **20** to block **24** is indicated at $\underline{\alpha}$ and the outputs from block **24** are indicated at $\underline{\alpha}$, $\underline{\alpha}^1$ and at $\alpha\rho$, $\alpha^1\rho$.

The signal $\underline{\alpha}$, $\underline{\alpha}^1$ is applied to the spectral whitening block **16** and the signal $\alpha\rho$, $\alpha^1\rho$ is applied to the impulse generation block **26**.

The output of spectral whitening block **16** is applied to the pitch analysis block **28** whose output is applied to quantizer block **30**. The quantized output $\hat{p}$ from quantizer **30** is applied to the bit packer **22** and also as a second input to the impulse response generation block **26**. The output of block **26**, indicated at h(n), is applied to the multiple analysis block **32**.

The perceptual weighting block **18** receives both outputs from block **24** and its output, indicated at Sp(n), is applied to an adder **34** which also receives the output r(n) from a ringdown generator **36**. The ringdown component r(n) is a fixed signal due to the contributions of the previous frames. The output x(n) of the adder **34** is applied as a second input to the multipulse analysis block **32**. The two outputs $\hat{E}$ and $\hat{G}$ of the multipulse analysis block **32** are fed to the bit packing block **22**.

The signals $\underline{\alpha}$, $\underline{\alpha}^1$, p and $\hat{E}$, $\hat{G}$ are fed to the perceptual synthesizer block **38** whose output y(n), comprising the combined weighted reflection coefficients, quantized spectral coefficients and multipulse analysis signals of previous frames, is applied to the block delay N/2 **40**. The output of block **40** is applied to the ringdown generator **36**.

The output of the block **22** is fed to the synthesizer/postfilter **42**.

The operation of the aforesaid system is described as follows: The original speech is digitized using sample/hold and A/D circuitry **44** comprising a sample and hold block **46** and an analog to digital block **48**. (FIG. **2**). The sampling rate is 8 kHz. The digitized speech signal, s(n), is analyzed on a block basis, meaning that before analysis can begin, N samples of s(n) must be acquired. Once a block of speech samples s(n) is acquired, it is passed to the preemphasis filter **12** which has a z-transform function

$$P(z)=1-\alpha^* z^{-1} \tag{1}$$

It is then passed to the LPC analysis block **14** from which the signal K is fed to the reflection coefficient quantizer and LPC converter whitening block **20**, (shown in detail in FIG. **3**). The LPC analysis block **14** produces LPC reflection coefficients which are related to the all-pole filter coefficients. The reflection coefficients are then quantized in block **20** in the manner shown in detail in FIG. **5** wherein two sets of quantizer tables are previously stored. One set has been designed using training databases based on voiced speech, while the other has been designed using unvoiced speech. The reflection coefficients are quantized twice; once using the voiced quantizer **48** and once using the unvoiced quantizer **50**. Each quantized set of reflection coefficients is converted to its respective spectral coefficients, as at **52** and **54**, which, in turn, enables the computation of the log-spectral distance between the unquantized spectrum and the quantized spectrum. The set of quantized reflection coefficients which produces the smaller log-spectral distance shown at **56**, is then retained. The retained reflection coefficient parameters are encoded for transmission and also converted to the corresponding all-pole LPC filter coefficients in block **58**.

Following the reflection quantization and LPC coefficient conversion, the LPC filter parameters are interpolated using the scheme described herein. As previously discussed, LPC analysis is performed on speech of block length N which corresponds to N/8000 seconds (sampling rate=8000 Hz). Therefore, a set of filter coefficients is generated for every N samples of speech or every N/8000 sec.

In order to enhance spectral trajectory tracking, the LPC filter parameters are interpolated on a sub-frame basis at block **24** where the sub-frame rate is twice the frame rate. The interpolation scheme is implemented (as shown in detail in FIG. **6**) as follows: let the LPC filter coefficients for frame k−1 be α^0 and for frame k be α^1. The filter coefficients for the first sub-frame of frame k is then

$$\underline{\alpha}=(\underline{\alpha}^0+\underline{\alpha}^1)/2 \tag{2}$$

methods (U.S. Pat. No. 4,701,954). However, such closed loop methods are computationally expensive. In the present invention the pitch analysis procedure indicated by block **28**, is performed in an open loop manner on the speech spectral residual signal. Open loop methods have reduced computational requirements. The spectral residual signal is generated using the inverse LPC filter which can be represented in the z-transform domain as A(z); A(z)=1/H(z) where H(z) is the LPC all-pole filter. This is known as spectral whitening and is represented by block **16**. This block **16** is shown in detail in FIG. **3**. The spectral whitening process removes the short-time sample correlation which in turn enhances pitch analysis.

A flow chart diagram of the pitch analysis block **28** of FIG. **1** is shown in FIG. **7**. The first step in the pitch analysis process is the collection of N samples of the spectral residual signal. This spectral residual signal is obtained from the pre-emphasized speech signal by the method illustrated in FIG. **3**. These residual samples are appended to the prior K retained residual samples to form a segment, r(n), where $-K \leqq n \leqq N$.

The autocorrelation Q(i) is performed for $\tau_1 \leqq i \leqq \tau_h$ or

$$Q(i) \overset{N}{\underset{n=-K}{=}} \Sigma r(n)r(n-i) \qquad \tau_1 \le i \le \tau_h \tag{3}$$

The limits of i are arbitrary but for speech sounds a typical range is between 20 and 147 (assuming 8 kHz sampling). The next step is to search Q(i) for the max value, M_1, where

$$M_1=\max(Q(i))=Q(k_1) \tag{4}$$

The value k is stored and $Q(k_1-1)$, $Q(k_1)$ and $Q(K_1+1)$ are set to a large negative value.

We next find a second value M_2 where

$$M_2=\max(Q(i))=Q(k_2) \tag{5}$$

The values k_1 and k_2 correspond to delay values that produce the two largest correlation values. The values k_1 and k_2 are used to check for pitch period doubling. The following algorithm is employed: If the ABS $(k_2-2^*k_1)<C$, where C can be chosen to be equal to the number of taps (3 in this invention), then the delay value, D, is equal to k_2 otherwise $D=k_1$. Once the frame delay value, D, is chosen the 3-tap gain terms are solved by first computing the matrix and vector values in eq. (6).

$$\begin{bmatrix} \Sigma r(i)r(n-\tau-1) \\ \Sigma r(n)r(n-i) \\ \Sigma r(n)r(n-i+1) \end{bmatrix} = \begin{bmatrix} \Sigma r(n-i-1)r(n-i-1) & \Sigma r(n-i)r(n-i-1) & \Sigma r(n-i+1)r(n-i-1) \\ \Sigma r(n-i-1)r(n-i) & \Sigma r(n-i)r(n-i) & \Sigma r(n-i+1)r(n-i) \\ \Sigma r(n-i-1)r(n-i+1) & \Sigma r(n-i)r(n-i+1) & \Sigma r(n-i+1)r(n-i+1) \end{bmatrix} \tag{6}$$

and α^1 parameters are applied to the second sub-frame. Therefore a different set of LPC filter parameters are available every 0.5*(N/8000) sec.

Pitch Analysis

Prior methods of pitch filter implementation for multipulse LPC coders have focused on closed loop pitch analysis

The matrix is solved using the Cholesky matrix decomposition. Once the gain values are calculated, they are quantized using a 32 word vector codebook. The codebook index along with the frame delay parameter are transmitted. The $\hat{P}$ signifies the quantized delay value and index of the gain codebook.

Excitation Analysis

Multipulse's name stems from the operation of exciting a vocal tract model with multiple impulses. A location and amplitude of an excitation pulse is chosen by minimizing the mean-squared error between the real and synthetic speech signals. This system incorporates the perceptual weighting filter **18**. A detailed flow chart of the multipulse analysis is shown in FIG. **8**. The method of determining a pulse location and amplitude is accomplished in a systematic manner. The basic algorithm can be described as follows: let h(n) be the system impulse response of the pitch analysis filter and the LPC analysis filter in cascade; the synthetic speech is the system's response to the multipulse excitation. This is indicated as the excitation convolved with the system response or

$$\hat{s}(n)=\sum_{k=1}^{n} ex(k)h(n-k) \tag{7}$$

where ex(n) is a set of weighted impulses located at positions n_1, n_2, . . . n_j or

$$ex(n)=\beta_1\delta(n-n_1)+\beta_2\delta(n-n_2)+\ldots+\beta_j\delta(n-n_j) \tag{8}$$

The synthetic speech can be re-written as

$$\hat{s}(n)=\sum_{j=1}^{j}\beta_j h(n-n_j) \tag{9}$$

In the present invention, the excitation pulse search is performed one pulse at a time, therefore j=1. The error between the real and synthetic speech is

$$e(n)=s_p(n)-\hat{s}(n)-r(n) \tag{10}$$

The squared error

$$E=\sum_{n=1}^{N} e^2(n) \tag{11}$$

or

$$E=\sum_{n=1}^{N}(s_p(n)-\hat{s}(n)-r(n))^2 \tag{12}$$

where $s_p(n)$ is the original speech after pre-emphasis and perceptual weighting (FIG. **4**) and r(n) is a fixed signal component due to the previous frames' contributions and is referred to as the ringdown component.

FIGS. **10** and **11** show the manner in which this signal is generated, FIG. **10** illustrating the perceptual synthesizer **38** and FIG. **11** illustrating the ringdown generator **36**. The squared error is now written as

$$E=\sum_{n=1}^{N}(x(n)-\beta_1 h(n-n_j))^2 \tag{13}$$

where x(n) is the speech signal $s_p(n)$−r(n) as shown in FIG. **1**.

$$E=S-2BC+B^2H \tag{14}$$

where

$$C=\sum_{n=1}^{N-1}x(n)h(n-n_j) \tag{15}$$

and

$$S=\sum_{n=1}^{N-1}x^2(n) \tag{16}$$

and

$$H=\sum_{n=1}^{N-1}h(n-n_1h(n-n_1) \tag{17}$$

The error, E, is minimized by setting the dE/dB=0 or

$$dE/dB=-2C+2HB=0 \tag{18}$$

or

$$B=C/H \tag{19}$$

The error, E, can then be written as

$$E=S-C^2/H \tag{20}$$

From the above equations it is evident that two signals are required for multipulse analysis, namely h(n) and x(n). These two signals are input to the multipulse analysis block **32**.

The first step in excitation analysis is to generate the system impulse response. The system impulse response is the concatentation of the 3-tap pitch synthesis filter and the LPC weighted filter. The impulse response filter has the z-transform:

$$H_p(z)=\frac{1}{1-\sum_{i=1}^{3}b_i z^{-\tau-i}}\;\frac{1}{1-\sum_{\tau=1}^{\rho}\alpha_i\mu^i z^{-i}} \tag{20}$$

The b values are the pitch gain coefficients, the α values are the spectral filter coefficients, and μ is a filter weighting coefficient. The error signal, e(n), can be written in the z-transform domain as

$$E(z)=X(z)-BH_p(z)z^{-n1} \tag{21}$$

where X(z) is the z-transform of x(n) previously defined.

The impulse response weight β, and impulse response time shift location n, are computed by minimizing the energy of the error signal, e(n). The time shift variable n, (1=1 for first pulse) is now varied from 1 to N. The value of n_1 is chosen such that it produces the smallest energy error E. Once n_1 is found β_1 can be calculated. Once the first location, n_1 and impulse weight, β_1, are determined the synthetic signal is written as

$$\hat{s}(n)=\beta_1 h(n-n_1) \tag{22}$$

When two weighted impulses are considered in the excitation sequence, the error energy can be written as

$$E=\Sigma(x(n)-\beta_1 h(n-n_1)-\beta_2 h(n-n_2))^2$$

Since the first pulse weight and location are known, the equation is rewritten as

$$E=\Sigma(x'(n)-\beta_2 h(n-n_2))^2 \tag{23}$$

where

$$x'(n)=x(n)-\beta_1 h(n-n_2) \quad (24)$$

The procedure for determining β_2 and n_2 is identical to that of determining β_1 and n_1. This procedure can be repeated p times. In the present instancetion p=5. The excitation pulse locations are encoded using an enumerative encoding scheme.

Excitation Encoding

A normal encoding scheme for 5 pulse locations would take 5*Int($\log_2$ N+0.5), where N is the number of possible locations. For p=5 and N=80, 35 bits are required. The approach taken here is to employ an enumerative encoding scheme. For the same conditions, the number of bits required is 25 bits. The first step is to order the pulse locations (i.e. 0L1≦L2≦L3≦L4≦L5≦N−1 where L1=min (n_1, n_2, n_3, n_4, n_5) etc.). The 25 bit number, B, is:

$$B=\binom{L1}{1}+\binom{L2}{2}+\binom{L3}{3}+\binom{L4}{4}+\binom{L5}{5}$$

Computing the 5 sets of factorials is prohibitive on a DSP device, therefore the approach taken here is to pre-compute the values and store them on a DSP ROM. This is shown in FIG. **12**. Many of the numbers require double precision (32 bits). A quick calculation yields a required storage (for N=80) of 790 words ((N−1)*2*5). This amount of storage can be reduced by first realizing $\binom{L1}{1}$ is simply L1; therefore no storage is required. Secondly, $\binom{L2}{2}$ contains only single precision numbers; therefore storage can be reduced to 553 words. The code is written such that the five addresses are computed from the pulse locations starting with the 5th location (Assumes pulse location range from 1 to 80). The address of the 5th pulse is 2*L5+393. The factor of 2 is due to double precision storage of L5's elements. The address of L4 is 2*L4+235, for L3, 2*L3+77, for L2, L2-1. The numbers stored at these locations are added and a 25-bit number representing the unique set of locations is produced. A block diagram of the enumerative encoding schemes is listed.

Excitation Decoding

Decoding the 25-bit word at the receiver involves repeated subtractions. For example, given B is the 25-bit word, the 5th location is found by finding the value X such that

$$B-\binom{79}{5}<0$$

$$\vdots$$

$$B-\binom{X}{5}<0$$

$$B-\binom{X-1}{5}>0$$

then L5=x-1. Next let

$$B=B-\binom{L5}{5}$$

The fourth pulse location is found by finding a value X such that

$$B-\binom{L5-1}{4}<0$$

$$\vdots$$

$$B-\binom{X}{4}<0$$

$$B-\binom{X-1}{4}>0$$

then L4=X−1. This is repeated for L3 and L2. The remaining number is L1.

The invention claimed is:

1. A method for determining linear predictive coding filter parameters for encoding a voice signal, the method comprising:

sampling a voice signal;

grouping the samples into a plurality of frames;

generating a plurality of reflection coefficients for each frame of samples;

generating spectral coefficients from said quantized reflection coefficients;

selecting a quantized reflection coefficient having the smallest log-spectral distance between a quantized spectrum and an unquantized spectrum; and

converting the selected quantized reflection coefficient to linear predictive coding (LPC) filter coefficients.

2. The method of claim **1** further comprising the step of interpolating the LPC filter coefficients on a sub-frame basis.

3. The method of claim **2** wherein each frame is divided into two frames and the LPC filter coefficients for the first sub-frame is an average of LPC filter coefficients of a current frame and a previous frame.

4. The method of claim **1** wherein the reflection coefficients are quantized by a voiced quantizer and an unvoiced quantizer.

5. The method of claim **4** wherein the reflection coefficients are quantized using a quantization table.

6. An apparatus for determining linear predictive coding filter parameters for encoding a voice signal, the apparatus comprising:

a sampler for sampling a voice signal;

an analyzer for generating a plurality of reflection coefficients for each frame of samples, each frame comprising a plurality of samples;

a quantizer for quantizing the reflection coefficients and for generating spectral coefficients from the quantized reflection coefficients;

a selection unit for selecting a quantized reflection coefficient having the smallest log-spectral distance between a quantized spectrum and an unquantized spectrum; and,

a conversion unit for converting the selected quantized reflection coefficient to linear predictive coding (LPC) filter coefficients.

7. The apparatus of claim **6** further comprising an interpolator for interpolating the LPC filter coefficients on a sub-frame basis.

8. The apparatus of claim **7** wherein each frame is divided into two frames and the LPC filter coefficients for the first sub-frame is an average of LPC filter coefficients of a current frame and a previous frame.

9. The apparatus of claim **6** wherein the quantizer comprises a voiced quantizer and an unvoiced quantizer.

10. The apparatus of claim **9** wherein the quantizer comprises a quantization table.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,013,270 B2
APPLICATION NO. : 10/924398
DATED : March 14, 2006
INVENTOR(S) : Lin et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

ON THE TITLE PAGE

At Item (75), Inventors, page 1, left column, line 2, after "**M. McCarthy**", delete "Lafeyette" and insert therefor --Lafayette--.

IN THE SPECIFICATION:

At column 1, line 66, after "an 8", delete "kbps" and insert therefor --Kbps--.

At column 2, line 32, after "an 8", delete "kbps" and insert therefor --Kbps--.

At column 3, line 10, after "is 8", delete "kHz" and insert therefor --KHz--.

At column 4, line 33, after "assuming 8", delete "kHz" and insert therefor --KHz--.

At column 6, line 34, after the first use of the word "the", delete "concatentation" and insert therefor --concatenation--.

At column 6, line 52, after the word "location", delete "n," and insert therefor --n_1--.

At column 6, line 53, after the word "variable", delete "n," and insert therefor --n_1--.

At column 7, line 6, after the word "present", delete "instancetion" and insert therefor --instance--.

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INVENTOR(S) : Lin et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 8, lines 3, 4, 5, delete “B = : (L5 -1/4) < 0” and insert therefor

--B = (L5 - 1 / 4) < 0 --.

Signed and Sealed this

Twenty-sixth Day of December, 2006

JON W. DUDAS
Director of the United States Patent and Trademark Office